

## Endovascular Grafting of Complex Aortic Aneurysms with a Modular Side Branch Stent-graft System in a Porcine Model

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**Objectives.** To evaluate and refine a stent-graft system with side branches for treatment of aneurysms with essential branch arteries.

**Methods.** In a porcine model ( $n = 4$ ) supra- and juxta-renal aortic aneurysms were created by suturing an artificial patch onto an anterior aortotomy. Angiography was performed to determine the exact location of the renal arteries. Accordingly, fenestrations were created in an appropriately sized aortic stent-graft. Initial deployment of the aortic graft is partial, whereby the top stent is secured in a cap and distal stents are being restrained, thus ensuring longitudinal and rotational manoeuvrability during alignment of the branch arteries. Separate branch grafts with silicone flanges for connection with the main stent-graft are subsequently placed in the renal arteries followed by full deployment of the main stent-graft. Outcome was evaluated by postoperative angiography and autopsy results and by measuring operating time, blood loss and use of contrast agent.

**Results.** Branched grafts were placed successfully in all trials. The median endovascular procedure time was 126 min (90–160), with 575 ml (400–800) blood loss and 65 ml (50–80) contrast agent use. Angiographically, all aneurysms were excluded without signs of endoleak and all renal arteries were patent. At autopsy, the main stent-graft and all side branches were adequately placed with intact connections between main stent-graft and branch grafts.

**Conclusions.** In this model, endovascular repair of complex aneurysms using a modular branch graft system is feasible in a reliable, predictable and timely fashion.

**Key Words:** Aortic aneurysm; Stent-graft; Talent aortic graft; Renal artery perfusion.

### Introduction

Aneurysms that involve segments of the aorta containing essential branch arteries, such as supra-renal, thoraco-abdominal and aortic-arch aneurysms, may pose difficult challenges to both surgeon and patient. Despite recent strides in surgical technique and peri-operative care, morbidity and mortality for repair of these aneurysms is still considerable.<sup>1–3</sup> Thus, with these extended aneurysms in particular lies a potential for improvement if repair could be accomplished via minimally invasive, endoluminal methods. Reports of endovascular techniques of complex aneurysm repair containing essential branch arteries have been limited to animal studies and incidental case reports.<sup>4–7</sup> In the latter, technically demanding and time consuming procedures are being described that to date have not been reproduced by others. The complex devices were

in most cases hand made and, therefore, unsuitable for use in a conventional endovascular unit.

The aim of this study was to develop and test, in cooperation with a major stent-graft manufacturer, a conventional, custom made branch graft system, that can be placed in a reliable, predictable and timely manner. If such a system would become commercially available, inclusion criteria for endovascular repair could potentially be extended to no-neck infrarenal aneurysms, aorto-iliac, as well as aortic arch and thoraco-abdominal aneurysms.

### Materials and Methods

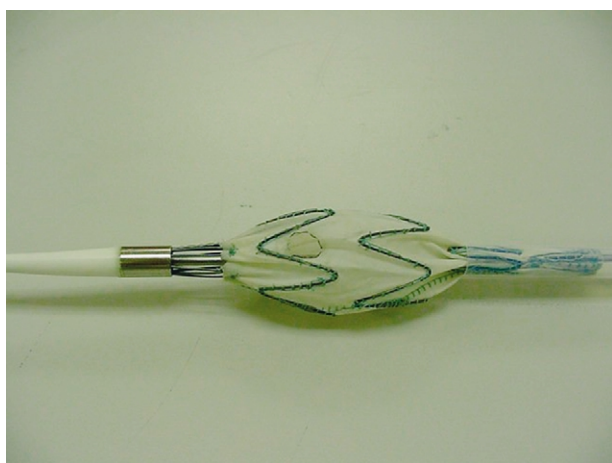
#### *Stent-graft system*

The device is a modular system containing a main stent-graft and separate side branches. The main stent-graft is composed of a Talent™ stent-graft (Medtronic AVE, Santa Rosa, CA, USA) customized with two fenestrations to match the renal artery origins (Fig. 1). Radiopaque markers are incorporated in the main

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**Fig. 1.** View of a fenestrated aortic stent-graft. Note the flexible radiopaque ring around the fenestration.



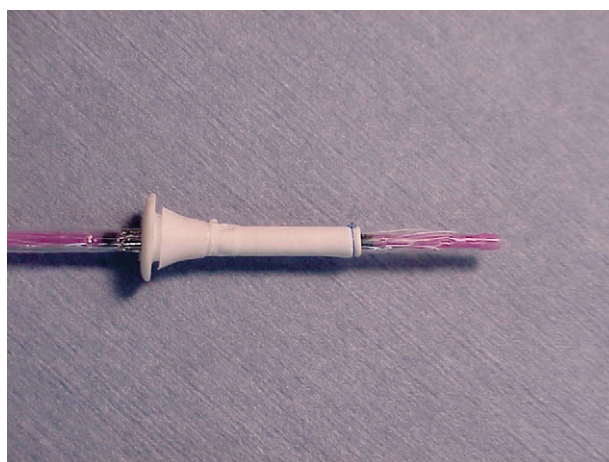
**Fig. 2.** The aortic stent-graft partially deployed by constraining the bare stent with a spindle and sleeve just below the tip of the introducer device. When the device is unsheathed, the bare top stent remains securely constrained in the sleeve, allowing continued manipulation to align the fenestrations with the vessel ostia.

graft to aid in accurate alignment with the arterial ostia. The delivery device is equipped with a partial deployment feature consisting of a bare top stent constrained by a spindle and sleeve (Fig. 2). Restraining sutures have been placed around the main graft to allow optimal maneuverability following initial deployment.

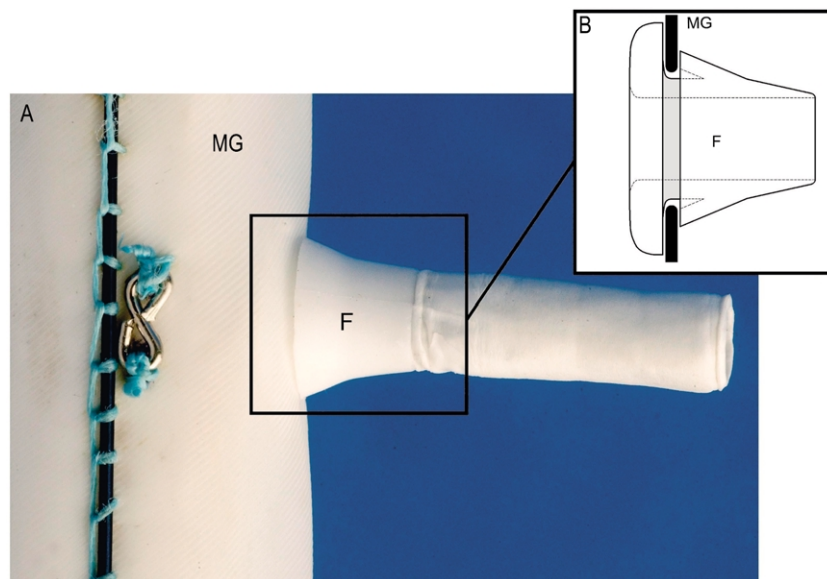
The side branch grafts consist of a balloon expandable stent, mounted on a non-compliant balloon, and covered with an ePTFE tube that is overmolded with a silicone flange (Fig. 3). The ePTFE is held to the stent by an additional constraining suture that will brake when the branch graft is deployed. The silicone flanges are designed to easily slide into the fenestration, lock into place and create a seal between the main stent-graft and the side branch graft (Fig. 4).

#### *Operative procedures*

Once final adjustments to materials and techniques had been made, and successful grafting of a single branch artery was completed in a pig with an infra renal aneurysm, four fully conditioned Yorkshire pigs were obtained from a single vendor and underwent a 5 day pre-operative conditioning period. In four consecutive experiments, all animals underwent two operative procedures during the same anesthetic period: (1) creation of a complex aortic aneurysm (2) endovascular repair of the aneurysm. All experiments were conducted using the guidelines published in the Guide for the Care and Use of Laboratory Animals (NIH publication 85-23, revised 1985). The study



**Fig. 3.** The side branch mounted on a catheter. The branch consists of a bare stent covered with an ePTFE tube overmolded with a silicone flange. The ePTFE is constrained by a suture and the flange specially designed to create a water tight seal between main body and branch graft.



**Fig. 4.** (A) The expanded side branch in position, sealed within the main graft (MG). (B) Schematic drawing of the flange (F) in detail.

protocol was approved by our institution's Animal Care and Use Committee.

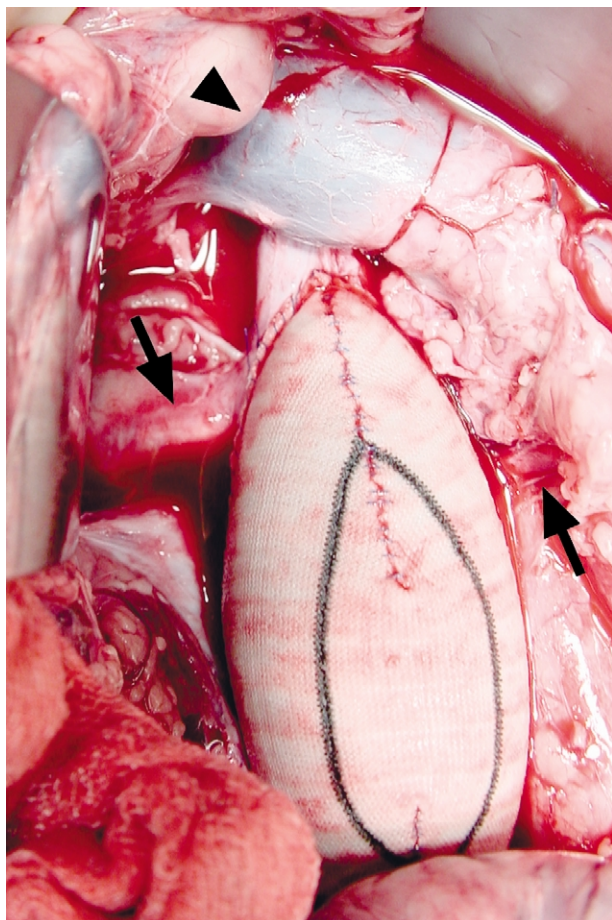
#### *Creation of the aneurysm*

Pigs of 90 kg (70–100) were pre-anaesthetized with a mixture of intramuscular ketamine (800 mg), midazolam (35 mg) and atropine (1 mg). Endotracheal intubation was performed following a intravenous dose of fentanyl (150 µg) and ethomidate (40 mg). General anaesthesia was continued with a mixture of intravenous fentanyl (500 µg/h), midazolam (20 mg/h) and pancuronium (20 mg/h) and inhaled isoflurane (2.4%). Tidal volume was initially set at 10 ml/kg, and respiratory rate at 13 per minute. These initial parameters were modified after serial blood gas measurements to keep the pCO<sub>2</sub> between 25 and 35, and the pH within normal limits. A jugular venous and carotid arterial access was obtained prior to the procedure. The electrocardiogram, carotid blood pressure, central venous pressure, blood gases, urine output, transcutaneous oxygen saturation and body temperature were monitored throughout the entire procedure. Glucose and Ringer's lactate solutions were administered for hydration. The surgical procedure of creating an aneurysm was previously described in a dog model.<sup>4</sup> In short, a longitudinal aortotomy was made and an elliptic artificial patch was sewn onto the aortotomy proximally starting above or at the level of the renal arteries (Fig. 5).

#### *Endovascular aneurysm repair*

During the endovascular procedure, blood loss, contrast use and operation time was monitored. Incisions were made in the left and right groin and common femoral arteries isolated. Following systemic heparinization (bolus of 5000 IU and 10,000 IU/h continuously), using the Seldinger technique, a.035" guide wire was entered into the right femoral artery and advanced into the supra renal aorta under fluoroscopic control (BV Pulsera, Philips Medical Systems, Andover, MA, USA). A sizing catheter was advanced over the guidewire and digital subtraction angiography was performed (Fig. 6). The diameter of the aorta, length of the aneurysm and location of the renal artery origins were measured (Table 1). Accordingly, 4 mm diameter fenestrations were created in an appropriately sized aortic stent-graft (diameter 14 mm, length 93 mm). The main stent-graft was placed in an introducer sheath (14F) and advanced over a.035" stiff guidewire (Back-up Meier, Boston Scientific, Natick MA, USA) into the aorta under fluoroscopic control. Subsequently, the sheath was retracted and the stent-graft partially deployed as described above. Partial deployment allows cannulation of the main graft from below without committing to definitive placement in the aorta. At this time, the device can still be rotated, or moved proximally or distally for proper alignment of the fenestrations with the vessel ostia. After retraction of the introducer sheath, a 16F sheath was introduced in the left femoral artery and a.035"





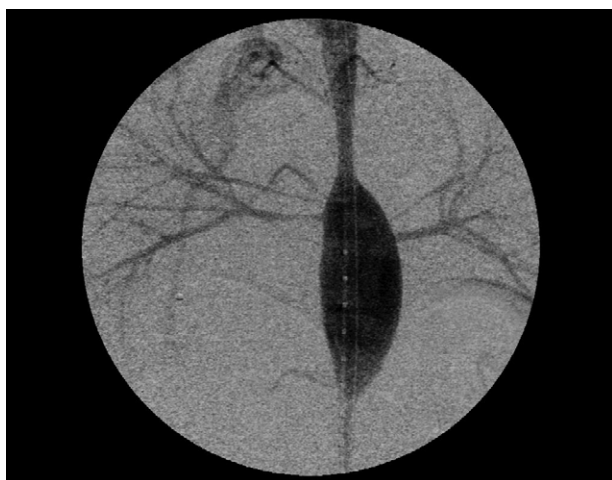
**Fig. 5.** Supra renal aortic aneurysm created by suturing an artificial patch onto an anterior aortotomy. Note the renal arteries (arrows) and left renal vein (arrowhead).

guidewire and 5F directional catheter was used to gain access to the main graft. Using the same wire and catheter, the renal artery was cannulated through the fenestration in the main stent-graft. The side branch was placed into an introducer sheath via a loading cartridge that folds the flange, and reduces its profile. The side branch catheter was then tracked over an .035" guidewire, through the main stent-graft fenestration into the renal artery. By pushing the graft into the renal artery, the special flange design assures for a tight connection between main stent-graft and branch graft (Fig. 4).

An integrated balloon was inflated to 3 atm. to deploy the stent to secure the landing site in the renal artery. The diameter of the side branch (5 mm) was oversized by 1 mm to achieve an effective sealing. Subsequently, the same procedure was performed for remaining branch arteries. Thereafter, the main stent-graft was fully deployed by unlocking the partial deployment mechanism and by inflating a non-compliant balloon (6 atm.) at the level of the landing sites and fenestrations. Extensions were placed distally in the main graft until distal fixation in the aorta was completed. As soon as the aneurysm was excluded from the circulation a completion angiography was performed (Fig. 7). Finally, the pigs were euthanised and at autopsy the aorta and aneurysm were carefully resected and the position of the device was photographed (Fig. 8).

## Results

The median endovascular procedure time was 126 min (90–160), with 575 ml (400–800) blood loss



**Fig. 6.** Angiogram of the created supra renal aortic aneurysm.



**Fig. 7.** Completion angiogram. The renal arteries are patent and no contrast is visible in the aneurysm sac.

Table 1. Summary of animal and stent-graft data

Animal no.	Weight (kg)	Diameter (mm)		Aneurysm length (mm)	Aneurysm type	Side branches	Distance (mm)	
		Aorta	Aneurysm				A	B
1	100	12	30	75	Infra renal 'no neck'	2	3	0
2	70	10	35	80	Infra renal 'no neck'	1	8	X
3	95	10	30	80	Supra renal	2	15	10
4	95	12	35	80	Supra renal	2	14	8

Distance A, axial distance between the beginning of the aneurysm and the most cranial artery; distance B, axial distance between both renal arteries.

and 65 ml (50–80) contrast agent use. The median cannulation time for each side branch graft placement was 34 min (20–60). Angiographically, all aneurysms were excluded from aortic flow without signs of endoleak and all renal arteries were patent after the procedure (Fig. 7). At autopsy, the main stent-graft and all side branches were adequately placed with intact connections between main stent-graft and branches (Fig. 8).

### Discussion

To date, reports on the use of branched stent-graft systems for endovascular aneurysm exclusion have been limited to incidental small series and case reports from highly skilled pioneers. The devices described are mostly home made or put together with various components that have been initially designed for other purposes.<sup>4–7</sup> In these studies, considerable technical difficulties were encountered, procedure time, contrast use and morbidity were significant and moreover the techniques described have not been reproduced by others.

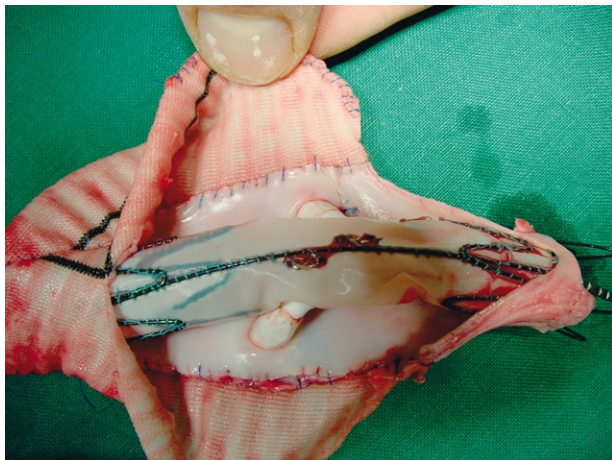


Fig. 8. Post mortem specimen. The aorta has been opened longitudinally through the patch. Note the side branches connected to the main graft and located in the renal arteries.

In endovascular repair of complex aneurysms the optimal positioning of the main stent-graft is of prime importance. To avoid occlusion of essential branch arteries fenestrations should be positioned careful at artery origins. Chuter *et al.* cited concerns about this subject when a system with fenestrations is used. Nevertheless, its feasibility has been shown in earlier studies by Anderson and Stanley.<sup>8,9</sup> In our device, cannulation of the renal arteries is performed before the main graft was fully deployed thereby creating additional manoeuvrability and reversibility of the procedure. For example, in our first animal procedure the main stent-graft had been initially deployed erratically with the left renal fenestration directed to the right, prohibiting cannulation of the corresponding renal artery. When the error was noted, the partially deployed main stent-graft could be easily rotated 180° allowing successful cannulation of both renal arteries. Additionally, we were keen to develop a side branch with an 'aerodynamic' configuration in the pre-deployment state allowing smooth insertion of the graft into the branch artery, thus perhaps reducing long branch graft cannulations times reported by others.<sup>5,7</sup>

The advantage of a modular system as described is mentioned earlier by Chuter *et al.*<sup>5</sup> A modular system can preserve branch artery perfusion during the entire procedure while the non-modular system described by Hosokawa causes considerable warm ischemia time when the main stent-graft is deployed and the side branches are not yet in place.<sup>6</sup>

Obviously, success of the procedure as described depends on accurate pre-operative measurements of images in three dimensions, followed by custom made graft manufacturing to obtain correct alignment of side holes and branch artery orifices. In our study measurements were made during creation of the aneurysm and using angiography. In case of future use in humans we have to adjust the size of the side branches up to 6–8 mm diameter after deployment using an 18–20F introducer.

Various studies reported concerns about stent-graft

migration in the long term.<sup>10,11</sup> Migration is associated with late aneurysm rupture, proximal endoleak, graft kinking and graft limb thrombosis.<sup>12,13</sup> Poorly incorporated stent-grafts because of the defective healing process of the aortic wall in aneurysmal disease combined with chronic longitudinal 'pulling and pushing' mechanical forces at the proximal and distal fixation sites are of concern.<sup>14,15</sup> In case of so-called 'no-neck aneurysms', the side branch device might increase proximal stability by creating a sufficient landing zone in healthy visceral aorta. Likewise, in case of distal migration of previously placed infrarenal stent-grafts, an extension with side branches in the renal arteries may secure proximal fixation.

Theoretically, branch graft placement as described in this study need not be limited to the renal arteries but, instead, can be implemented in aortic arch branches, visceral arteries, and internal iliacs, leading to a significant widening of the indication range for endovascular aneurysm repair.

In conclusion, in this model, endovascular repair of complex aneurysms using a modular branch graft system has been shown to be feasible in a reliable, predictable and timely fashion.

#### Acknowledgements

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